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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Henry AZIMA, et al.
Title:	RESONANT PANEL-FORM LOUDSPEAKER
Appl. No.:	09/752,830
Filing Date:	01/03/2001
Examiner:	Huyen D. Le
Art Unit:	2643

DECLARATION OF MARTIN COLLOMS

I, Martin Colloms, of London, England, declare as follows:

INTRODUCTION

1. I reside at 29 Flask Walk, London, NW3 1HH, Great Britain; I am an independent consulting engineer; I graduated from the University of Westminster, England, with a Bachelor of Science degree in Electrical Engineering, with honours; I am a chartered engineer; I have over twenty five years experience of the Hi-Fi electronics industry, as an engineer, as a product designer (about 130 designs produced for mass production), as a manager of companies operating in this field, and as an independent consultant; I regularly review products and write articles for the journal "Hi-Fi News and Record Review" (UK) and am Senior Contributing Editor to Stereophile magazine (USA); I have published many papers, in particular at Audio Engineering Society meetings; I have authored a design textbook entitled "High performance Loudspeakers", published by John Wiley, now in its fifth edition dated 1997; I am a contributing author to the textbook "The loudspeaker handbook", edited by John Borwick, published by Heinmann-Butterworth.

2. I am a consultant to New Transducers Limited (hereinafter "NXT"), the assignee of the above-captioned United States patent application to Azima, et al., No. 09/752,830, and am familiar with the technology disclosed and claimed therein. The application concerns panel-form resonant bending wave loudspeakers, which have become known as distributed mode (DM) loudspeakers. The claims of the application specify that at least a portion of the panel-form member is transparent, and that the vibration exciting transducer is mounted to an edge or marginal portion of the panel-form member.

HISTORICAL DEVELOPMENT OF LOUDSPEAKERS

3. Only a very few panel type speakers were available before 1995; the vast majority of speakers in use had conical and/or dome shaped radiating diaphragms. The out-of-plane, "cone" shape relates to the objective of making a stiff, light sound radiator of moderate cost, e.g., out of sheet paper or plastic material. The alternative dome shape tends to be used in smaller units, e.g., tweeters, and may be made from a variety of materials including resinated cloth and even metal foil.

4. These traditional moving coil driven "cone speakers" were and are very successful. They rely fundamentally on the principle of non-bending, pistonic operation, and date from the 1920s. A tubular voice coil is freely suspended for axial movement in a strong, concentric magnet gap, allowing to and fro motion. A light sheet of paper or plastic, not much thicker than ordinary good quality paper, is made in the shape of a shallow cone, is joined to the voice coil at the apex, and is freely suspended at the rim or edge using a compliant plastic, rubber or fabric surround. The latter is often in the form of accordion style pleats or a roll type (half-roll).

5. The conical shape is immensely stiffer than the flat sheet and allows the diaphragm which is so formed to operate as an essentially rigid structure over most of the frequency range – e.g., from below 50Hz in the bass to many kHz in the treble, in the case of a typical 4 or 5 inch driver – the entire diaphragm moving as a stiff unit so that distortion is minimised. Higher in the frequency range, where the sound is composed mainly of natural harmonics, the cone may then fail to act as one and various so-called "break-up" behaviours occur, with concentric and axial modes of vibration, these nonetheless dominated by the conical geometry.

6. In higher quality applications the frequency range may be separated by a crossover network so that two or more specialised drive units may be used, each adapted for the chosen frequency range. Thus a 5 inch mid-bass driver may crossover to a 1 inch titanium dome tweeter at about 3kHz. Such a tweeter can maintain the desired piston operation to well beyond audibility, even to 30 kHz in some examples.

7. Designers and inventors have struggled for years to engineer an attractive alternative, such as the flat panel, to the cone speaker. Where the radiating panel is flat, it allows slim speaker forms, a freedom from acoustic cavity effects, and depending on the type, further

valuable benefits such as wide radiation angles, full frequency response from one device and even inherent visual transparency.

8. The few panel speakers of this earlier period were of various types and many did not operate in bending. The best known non-bending type is the flat panel piston speaker. Here a costly, high quality composite structure is used for the diaphragm to try and obtain the highest possible frequency before it begins to "break up" or bend. Ordinary thin cone material, if flat, would begin bending from as low as 70Hz, and with increasing frequency the catastrophic lack of rigidity will result in irregular, severe resonances, imparting an uneven and failing frequency response.

9. By using a costly aerospace composite the stiffness of the flat diaphragm may be made so high that bending is deferred to a frequency beyond the intended working range. Pure piston operation is achieved in the working range. These speaker drivers do have a limited range on frequency span and are also limited on grounds of narrowing sound radiation (due to the natural acoustics of the particular diameter of the radiator). To cover the audible frequency response range, two or more such drivers would be used in graded sizes.

10. Two notable kinds of bending panel speaker were known before DM loudspeakers were developed. One is the Heron multi-resonant type (see, e.g., US 6,058,196), which only operates above the critical or coincidence frequency for the panel. Such a panel is rather large, very stiff, and of consequently low efficiency, and necessarily has restricted low frequency output. It is not designed for a particular modal distribution. Rather, it relies on the natural property of a panel whereby, at higher frequencies, the modal density is high enough for acceptable use as is. Heron is only known from the patent literature and has never been commercialised.

11. Another is the Bertagni type, which may be planar or may have a planar front but may be deeply contoured at the back to form a kind of energy terminating form, a solid cone when viewed in profile. See, e.g., US 5,425,107 and US 5,693,917. This cannot be regarded as a panel radiator of the ideal type – one of substantially uniform thickness, where ordered, bending wave operation is the objective and is subject to the ordered application of good physics and math. Both planar and conical forms of Bertagni speakers taught a hammer-like drive to the diaphragm, which was made of bonded granules of expanded polystyrene, and which provided a reducing radiating area with frequency. Thus, bending waves are not

allowed to propagate over the surface. They operate in "flexure," but not in free bending. Anti-resonance methods also taught include a "terminating channel" at the periphery and the use of masses placed at vibrationally active points to suppress resonances.

12. For the usual stiff, light flat pistonic diaphragm in the form of a circular plate, when bending begins, as it will as the frequency increases, the shape of the bending modes forms a series of concentric circles. The sparse modes dominate the sound output, which is very uneven and is considered unusable for a loudspeaker. This is because there is only one series or set of useful modes. A square plate behaves similarly with a degree of disc-like behaviour, while the lower bending frequencies for the square follow plate geometry and are coincident, i.e. the same for the two axes. Prior art panel speakers of this general type have traditional central drive and have far too few resonances at lower frequencies to be of any use.

13. However, suppose that we may specify or parametise the physical properties of the bending plate or panel which we want to use as a flat speaker radiator. We do so in such a way that more resonant modes are present, to try and fix the perennial problem of the uneven, gapped response. Also suppose that when specifying the parameters, e.g., the dimensions of length and width (or their bending wave equivalents), we can actually slide one set of modal frequencies (x axis) along the other (y axis) in frequency so that they interleave better. If we were to do so we will have devised a new method to create a panel speaker, where there is sufficient modal density and sufficiently even spacing of mode frequencies to construct satisfactorily uniform resonant frequency response. This development began in the fall of 1995 at NXT in Cambridge, UK, and is called Distributed Mode (DM). The technology has been patented worldwide, and improvements continue to receive patents. See, e.g., US 6,332,029.

14. With this development, which used the selection of bending wave parameters to create a designed modal distribution, came the matching proposal to analyse the physical distribution of the sets of modes over the surface of the bending panel, over the useful formant frequency range, e.g., up to 10 modes from the lowest frequencies in each primary axis. This provides the basis on which to choose useful locations to drive the panel, i.e. the point of excitation. This is generally off-centre but still relatively near the panel centre for good efficiency. In fact the teaching goes much further than this and, for example, considers modes or degrees of freedom in further axes, e.g., rotation, diagonal motion, etc.

15. The noted DM development has led to a substantial flowering of research in the field of bending wave panel speakers, and to a raft of academic papers and further patent applications. In fact, some 200 patent families have been set in train on this and related subjects since 1995. Millions of loudspeakers have now been made using the fundamental DM principles.

16. Early in the research program the problem of adapting the DM panel to an important use was tackled: an application for electronic displays. These would be used in a cathode ray tube environment. Projection and LCD use was also examined as to its usefulness.

OBSERVATIONS CONCERNING SPITZ (FR 2 649 575)

17. Prior art existed for transparent speaker panels. Perhaps the most practical and well explained of these was by Spitz for Thomson Consumer Electronics. See FR 2 649 575, which was filed in 1989 (and published in 1991), and its English translation (PTO 03 3564). Here practical electromagnetic exciters are employed at an edge of a transparent panel, which is placed in front of the display. At low to medium frequencies the significantly heavy, rigid panel (these panels cannot be the usual lightweight, skinned composites, instead they have to be solid transparent monoliths) acts as one, i.e. as a piston when it is set into motion. As explained earlier, a panel diaphragm of ordinary construction has real problems when it begins to "break up". From there upwards it enters the region of irregular bending for higher frequencies.

18. Spitz recognises this difficulty and offers a strategy to try and mitigate that unwanted result, which otherwise is likely to present as a severely irregular frequency response and poor sound. Without the means to order the resonances or the knowledge to drive them beneficially, Spitz follows the standard approach of the time, which is to try and make them go away. This is in complete contrast to DM and related teaching where bending wave resonances are positively encouraged, and beneficially driven.

19. In my opinion, Spitz seeks to operate his speaker as a pistonic type over a designed, operative range of frequencies. I make the following detailed observations concerning my understanding of the teachings of Spitz. Specific references are to the English translation (PTO 2003-3564). In the quoted passages, the italicized material in square brackets are my notes and comments.

(a) Teaching a piston type suspension for the speaker panel:

To facilitate the intended to and fro pistonic motion, Spitz ensures that the diaphragm is suspended on a conventional piston type support commonly known as a half-roll surround, of polymer or flexible rubber, to acoustically seal the edge to the frame or enclosure. Sealing is required to prevent the low frequencies from cancelling out, since piston speakers have sound output from the rear face that is anti-phase relative to that from the front.

See page 5, third full paragraph:

> The four edges of the screen are made integral with the cabinet [*i.e., an acoustic seal*] by a flexible joint [*i.e., a compliant suspension*] of the polymer tissue type (synthetic caoutchouc) embossed or rolled [*i.e., a rubber roll type suspension*] featuring a technology similar to that of the external suspensions of electrodynamic loud speakers [*i.e., conventional moving coil drivers*].

(b) Teaching to make the speaker panel rigid as a piston by choice of material, and yet have superior losses or damping to ameliorate possible resonances:
See page 5, last paragraph.

> Screen 2 is preferably made of transparent polymer of the PMMA or TPX type, or even lighter and presenting at once, superior mechanical losses and rigidity.

At the time TPX was hailed as a new speaker cone material with a favourable combination of high mechanical loss and very high stiffness.

(c) Teaching to help maintain piston operation by spreading the drive more evenly around the panel:

See page 6, lines 1-3.

> To symmetrize the constraint [*i.e., forces*] applied to the transparent screen several loud speaker motors can be used along its periphery ....

This is a well-known technique to inhibit bending resonance in a diaphragm.

(d) Teaching to keep the operating range of the panel in the low frequencies where the panel remains rigid, and thus has not entered the bending range:
See page 6, lines 3-6.

> [I]n all cases, the audio frequencies (acoustic frequencies) reproduce [sic] by that screen will not exceed several hundreds of hertz. The higher frequencies are reproduced by one or several loud speakers with small dimensions.

Note that at the higher frequencies, small loudspeakers will be used to carry the output, exactly as taught for conventional piston speakers used with a crossover network.

(e) <u>Teaching that where an inertial exciter is used, it should preferably energise the panel at low, i.e., pistonic frequencies</u>:

On page 10 Spitz introduces inertial exciters. Note that inertial exciters are known and are of several types. Many heavier, limited bandwidth versions are seen in the prior art; in particular Spitz indicates use of one of these where the coil assembly is mass loaded and the required inertial reaction force is actually communicated to the panel via the heavy magnet assembly. Such a magnet mass acts as a low pass or bass filter for the excitation carried to the panel. See Fig. 9. In my view this may be a deliberate design choice to try and restrict the otherwise wider operating range just to lower frequencies, where it seems clear that the panel is intended to be pistonic.

See page 10, final 5 lines:

> The invention also makes it possible to use inertial motors as shown in Figure 9.
>
> The inertial motors can be attached directly on the rear of the screen 2 [*loudspeaker panel*] without any support points. They work on the basis of the "action of mobile units 50, 51 reaction of support screen" principle by virtue of the equality of movement qualities … [*mass action and reaction; inertial reference mass*].

(f) <u>Teaching that bending resonances are to be minimised or avoided e.g. through the application of resonance damping, the fitting of anti-resonators at strategic positions where a resonance would otherwise be active, and the use of high loss materials, e.g., in the composition of the support or edge suspension</u>:

See page 11, lines 5 to 10:

> These motors [*i.e. inertial*] are very effective at frequencies that are lowered by some hundredths of Hz where they excite the resonance modes of the shell or the plate of the screen [*we know from plate physics that these shell modes must be at higher frequencies above first bending or breakup frequency, i.e., above the piston range*]; the latter are amortized [*reduced, suppressed*] by the usual techniques (inertial masses based at vibration centers [*these are anti-resonators*], joints with the screen support made of flexible and absorbent

materials, etc.) [*i.e., edge damping using mechanically lossy, flexible polymers and similar materials*].

20. Summarising, I understand from the Spitz patent that he proposes a solution to the problem of integrating a transparent, large area speaker diaphragm with a display. He teaches that the diaphragm, which is in the form of a rigid panel, should operate at low, bass frequencies, where someone normally skilled would understand it to behave as a unit device working like a conventional piston. The fitting of a piston-compatible roll-edge, free suspension is advised to support the diaphragm, which as usual is required to acoustically seal the edge of this bass panel to avoid cancellation at low frequencies. The possible problem of unwanted panel resonance is noted, together with several recommendations on how to construct the speaker in order to avoid such resonances and their effects. Spitz is concerned with avoiding the need for an ordinary separate bass enclosure for the low frequencies in order to make the display speaker assembly more compact. He does this by exploiting the large area available in front of the screen, provided of course that the respective moving panel diaphragm is transparent. Having achieved his pistonic bass speaker, the rest of the frequency range, the mid and high frequencies, can be reproduced by naturally smaller speaker units, whose small size allows easy placement in or on the rest of the structure.

Observations Concerning The Azima, et al. Application

21. When I consider application No. 09/752,830 to Azima, et al., I find very different teaching. This technology is founded on the intended bending wave action of panel loudspeaker diaphragms. It addresses the difficulties encountered for a transparent panel design in regard to the less than optimal, peripheral placement of the exciter, and offers solutions to useful coupling to available sets of bending modes. The awkward combination of display and bending wave speaker is addressed as a unit item where the panel is mounted, and not freely supported, in order to create a credible, practical unit and where the mounting includes restraint or clamping with the purpose of maximising the bending energy input from the exciters. In particular, where a transparent panel is of a particular aspect ratio, or otherwise, the amount and location of the panel restraint may be exploited to improve the distribution of bending wave modes for improved sound quality. (Note that restraint for a bending wave panel is not equivalent to the blocking effect on a moving piston. For a

bending wave panel a clamp acts as reflector. Energy is not lost; it is instead redirected as a different wave shape and distribution.)

CONCLUSIONS

22. I cannot find any patent-relevant connection between the patent of Spitz and the application of Azima, et al. While they both address the problem of a transparent speaker panel, they do so from quite different viewpoints.

23. Spitz consistently and persuasively teaches conventional pistonic speaker behaviour for a rigid panel, compliantly supported and sealed as a piston. He understands that bending resonances may well occur in a large panel despite measures, such as the use of multiple exciters arranged around the periphery, to keep the panel moving uniformly. He teaches several supplementary techniques to avoid, suppress and control these unwanted resonances should they occur in a design. The techniques are well known to piston diaphragm designers, and Spitz includes mass type anti-resonators placed at strategic locations, applied damping, for example at the edge of the transparent panel, perhaps to be combined with the compliant, flexible edge support; and finally the choice of panel material itself which should have high inherent mechanical loss for good self-damping in respect of resonances, as well as high rigidity to inhibit bending in the first place.

24. Azima, et al. come from the DM bending wave technology sector and have eschewed conventional piston technology. Their speaker is bending resonant from the start, pistonic action is to some degree inhibited by the design integers, not least because the physics indicates that radiation from pure bending is significantly more effective when the radiating panel is proximate to a display unit when compared with pistonic action. The relatively small air gap impedes piston operation, rendering it less effective. While no Spitz-type speakers were put into production, the solution presented in the Azima, et al. application has already resulted in the sale of hundreds of thousands of valuable and effective SOUNDVU® brand transparent bending wave loudspeakers of good sound quality, manufactured by NXT licensee NEC, and incorporated in their computers. NEC is one of the top computer makers and electronic companies in the world. Global NEC sales are quoted at $39 billion, and the SOUNDVU® brand designs are expanding rapidly at this time as the many products in which it is used cross over into home entertainment, DVD, movie replay and television.

I further declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: 1st December 2004

M. Colloms

Martin Colloms